Firefighting Chemicals

. . . NEW WEAPONS FOR THE FIRE SUPPRESSION CREW

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FIREFIGHTING CHEMICALS--NEW WEAPONS

FOR THE FIRE SUPPRESSION CREW

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"We felt like witch doctors," was the complaint made by a foreman whose tanker crew had been selected to test the fire fighting qualities of "viscous water" (water containing a thickening agent). A few months later the same foreman, thoroughly familiar with the material, was convinced that under many conditions viscous water was superior to plain water in controlling forest fires. This change of opinion was the result of a three-part cooperative study conducted during the summer and fall of 1960 in California and Nevada.

Use of chemical additives for water in forest fire control is not a new idea. The U. S. Forest Service began testing such materials for fire suppression in 1931, and studies in the United States have been conducted periodically ever since (Barrett, 1931; Truax, 1939). Yet use of chemical additives on fires has been limited until recently, for several reasons: difficulty of handling with conventional pumping equipment, cost of the chemicals, logistics, and the fact that some fire fighters were looking for a panacea. Recently, higher values of forest resources and the demand to reduce fire losses have forced foresters to take a new look at chemicals.

Experiments during Operation Firestop in 1954 showed that sodium calcium borate was the best fire fighting chemical tested at that time (Operation Firestop 1954). Operational tests in 1955 were aimed at applying borate slurry from firetrucks because firefighters believed that application to forest fuels would be more accurate and efficient in this manner. Borate proved to be quite abrasive to the types of pumps commonly used in firetrucks, and ground application was abandoned (Miller and Wilson, 1957). Then the air tanker program was launched. Air tankers now drop millions of gallons of chemicals on forest fires annually.

New interest in chemicals that might have ground application was stimulated when the Syracuse University Research Institute demonstrated that viscous water was about 4 times more effective than plain water in extinguishing certain laboratory fires (Aidun, 1960). At Syracuse, laboratory tests with small crib fires showed that when suppressed with water, all five cribs being tested rekindled at least once and some as many as four times. When extinguished with viscous water, 7 but of 9 cribs did not rekindle, and the remaining 2 rekindled only once.

Also, improvements and changes in pumps and mixing equipment solved many problems of handling chemicals.

Fire fighting agencies in California and Nevada 1/ decided in 1960 to pool their resources and conduct a series of observational tests with new materials in ground equipment. Here is what we found:

---Viscous water was more effective than plain water for controlling fires in most forest fuels and in keeping them from rekindling.

---A thick gel made with algin (derived from seaweed) and calcium chloride was even more effective than ordinary viscous water under some conditions.

---Foaming bentonite was superior to plain water for fires burning in heavy fuels but permitted fire to creep through matted grass and leaves.

---Diammonium phosphate solution thickened with a viscosity agent can make some forest fuels almost fireproof for a long period of time.

1/ Agencies cooperating in the experiments included the U. S. Forest Service--Region 5, the Nevada Division of Forestry, the Los Angeles County Fire Department and the California Division of Forestry. The Pacific Southwest Forest and Range Experiment Station of the Forest Service coordinated the project and conducted the laboratory fire tests. Several private chemical companies also cooperated in the study to a large degree.

FIELD TESTS

CHEMICALS TESTED

The following materials were tested for their ability to suppress fires and to retard the spread of fires:

Bentonite foam.--Volclay bentonite No. 200, American Colloid Company plus Dowfax 2A1 solution, Dow Chemical Company: 0.6 pounds bentonite per gallon of water and 4.0 pounds Dowfax per 100 gallons of water. Foamed volume seven times original volume.

Viscous water.--Water containing one of three kinds of thickening agent: (a) Sodium carboxymethylcellulose, 2WXH, DuPont--0.5 percent solution in water (called CMC); ET-460-4, Dow Chemical Company--0.5 percent solution in water (called ET-460-4); (c) Sodium alginate, either Keltex KNF, Kelco Company--0.8 percent solution in water--or Keltex FF--0.4 percent solution in water--same viscosity obtained with each algin.

Calcium alginate gel.--Sodium alginate (Keltex KNF), Kelco Company--0.8 percent solution in water (or 0.4 percent solution of Keltex FF)--plus calcium chloride (37 percent solution) at ratio of 1 part calcium chloride to about 300 parts of sodium alginate solution (called algin gel).

Chemical fire retardants.--Three different solutions of diammonium phosphate, (a) diammonium phosphate, Monsanto Chemical Company--12 percent solution--plus sodium CMC 2WXH, DuPont--0.5 percent solution in water (called CMC-DAP); (b) diammonium phosphate, Monsanto Chemical Company--12 percent solution in water, plus sodium alginate, Keltex FF, Kelco Company--0.6 percent solution in water (called algin--DAP); (c) diammonium phosphate, Shell Chemical Company--18 percent solution in water (called DAP).

TEST PROCEDURES

The field tests were conducted at four separate locations throughout the summer and early fall of 1960. Ignition techniques, methods of application, and flow rates were controlled as carefully as possible under the field conditions in an effort to make the tests uniform.

The earliest tests were held near Mariposa, California. For suppression tests, fires in cribs of railroad ties were sprayed with bentonite foam, CMC, ET-460-4, DAP, and CMC-DAP (fig. 1). Several other cribs were extinguished with water and plain bentonite slurry. Extinguishment time and radiation output were recorded for each fire. For tests of retardant effectiveness, the test liquid was sprayed on one end of a large pile of dry brush (fig. 2) and allowed half an hour or more to dry. The unsprayed end of the pile was ignited, and the fires were allowed to burn into the portion sprayed with retardant.

Figure 1.--Extinguishing a railroad tie crib fire with viscous water at a series of field tests held at Mariposa.

Figure 2.--Spraying viscous diammonium phosphate on end of a brush pile at the Mariposa field tests.

Another series of retardant tests, made in grass plots near Cathay, compared bentonite foam, CMC, and plain water. 2/ A strip along one end of each grass plot was treated with one of the chemicals. The treated strips then dried for 1, 2, or 3 hours. After drying the designated time, plots were ignited at the untreated end, and the fires were allowed to burn into the strips (fig. 3).

Grass plots near Flinn Springs were also used to test the retarding characteristics of algin-thickened water, algin gel, and algin-DAP. Procedures were the same as those used at Cathay.

Similar procedures were also used to test algin, algin gel, and algin-DAP in brush plots near Ramona (Phillips, 1961). The brush was buckwheat and sage; it stood about 4 to 5 feet high and produced very hot fires. Again, treated strips of the plots were allowed to dry 1, 2, and 3 hours before burning.

TEST RESULTS

The data from these tests were not suitable for statistical analysis. At the Mariposa tests, however, records of extinguishment time and radiation reduction indicate that there was a difference in suppressant effectiveness that appeared to be directly related to viscosity (fig. 4). The rate of rekindling was not measured but observers noticed that rekindling was slower and less frequent with viscous water, bentonite slurry, and bentonite foam than with plain water.

CMC-DAP and bentonite foam were the outstanding materials tested for retardant properties on the brush pile fires at Mariposa (table 1). The CMC-DAP completely stopped a test fire, and the unburned portion of the pile could not be ignited with a pneumatic flame thrower after several additional hours of drying. Bentonite foam that had dried 2-1/4 hours effectively stopped the spread of fire burning against the wind. However, unlike the brush treated with CMC-DAP, the treated portion of this pile could be ignited the next day.

In the Cathay grass plots, strips treated with CMC, bentonite foam, and water were all successful in stopping the fire after they had dried for 1 hour. After 2 hours of drying, however, none of these materials stopped the fire, and no significant retarding effect was observed.

2/ Phillips, C. B. Testing CMC as a fire retardant. State of California Dept. of Nat. Res., Div. of Forestry, Fire Control Experiments No. 2. Manuscript 1961.

Figure 3.--Igniting a grass plot to evaluate the retardant characteristics of viscous water.

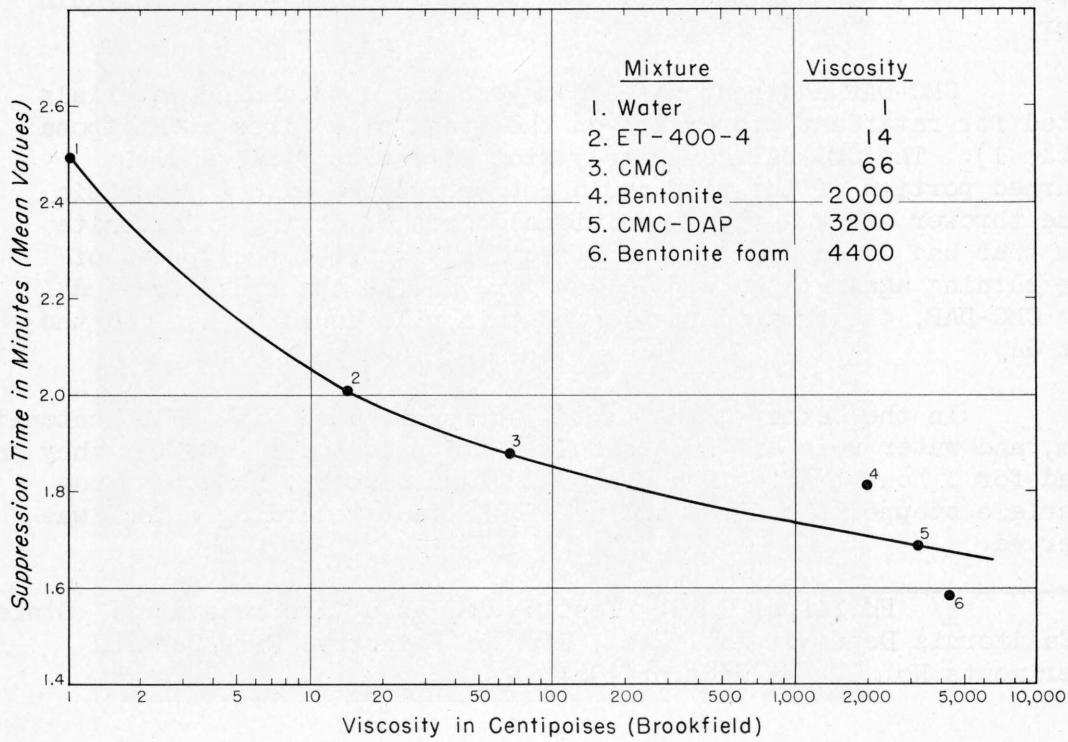

Figure 4.--Average time required to suppress crib fires by various materials tested at Mariposa.

Table 1.--Retardant effectiveness on brush piles

Test material	Fire burning with the wind: Fire stopped	Fire slowed	Fire not effected	Fire burning against the wind: Fire stopped	Fire slowed	Fire not effected
CMC[1/]	--	--	--	--	x	--
CMC-DAP[1/]	--	--	--	x	--	--
ET-460-4[1/]	--	--	--	--	x	--
DAP	--	--	x	x	--	--
Bentonite slurry	--	x	--	x	--	--
Bentonite foam[1/]	--	--	--	x	--	--
Water (control)	--	--	x	--	x	--

1/ Not tested in fires burning with the wind.

Algin, algin gel, and algin-DAP proved to be effective fire retardants at the Flinn Springs grass plots. Control strips treated with water failed to top fire spread at the end of 1 hour of drying and had no significant retarding effect. On the other hand, strips treated with algin stopped fire completely after 1 hour of drying, and slowed the fire at the end of 2 hours. Algin gel of a low viscosity stopped fire spread after 2 hours of drying, and a high viscosity algin gel after 3 hours of drying. Strips treated with algin-DAP stopped fires after 2 hours of drying. No tests of longer drying time were made with algin-DAP.

These same materials were also successful in the Ramona brush plot tests. Strips treated with algin stopped fires after 1 and 2 hours of drying but not after 3 hours. Algin gel with a medium viscosity stopped fires after 1 and 2 hours and slowed a fire after 3 hours of drying. A high viscosity algin gel completely stopped a fire after 3 hours of drying. Algin-DAP was tested in only one plot after it had dried for 2-1/3 hours and was wholly successful in stopping fire spread.

Algin gel was not developed for field testing until near the end of the fire season. It showed up well in field tests in grass and brush plots and in other tests, but somewhat crude application equipment prevented its being used operationally. Better equipment has been developed to permit further tests of the gel during the 1961 fire season.

OPERATIONAL TESTING

After the Mariposa tests, viscous water, bentonite foam, and algin-DAP were tried on an operational basis by four fire control agencies in California and Nevada during the 1960 fire season.

Nine forest-fire crews, picked for their interest in the study and the normally high fire occurrence in their areas, were assigned to the operational testing program. Each crew was supplied with an injector mixer loaned for test purposes by the Western Fire Equipment Company. Most mixers were mounted on the truck and piped into its plumbing system (figs. 5 and 6).

MATERIALS TESTED

The following materials, in most cases donated by the respective chemical companies, were tested under operational conditions:

Bentonite foam--Wyoming grade, 200 mesh, swelling bentonite clay plus Dowfax 2A1 solution, Dow Chemical Company--0.5 pounds bentonite per gallon of water and 4.0 pounds Dowfax per 100 gallons of water. Tested by two California Division of Forestry crews--Mariposa Forest Fire Station (Mariposa

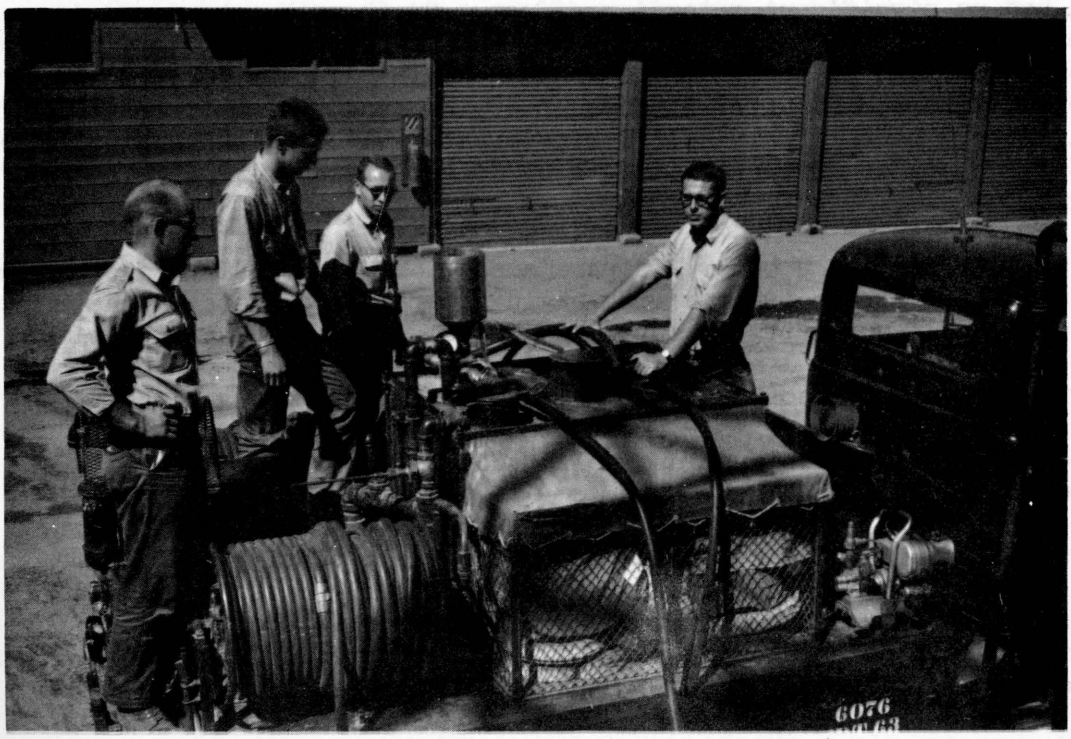

Figure 5.--Viscous water mixing equipment installed on a U. S. Forest Service fire truck at Mt. Shasta Ranger Station.

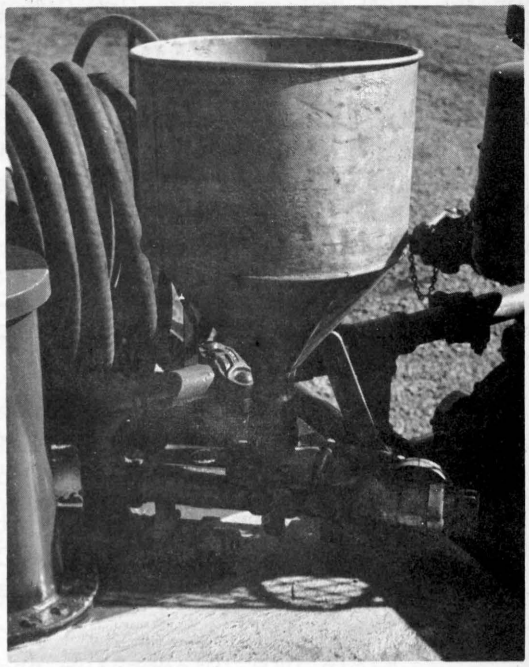

Figure 6.--
Closeup of viscous water mixing equipment installed on a California Division of Forestry truck at Cathay Fire Station.

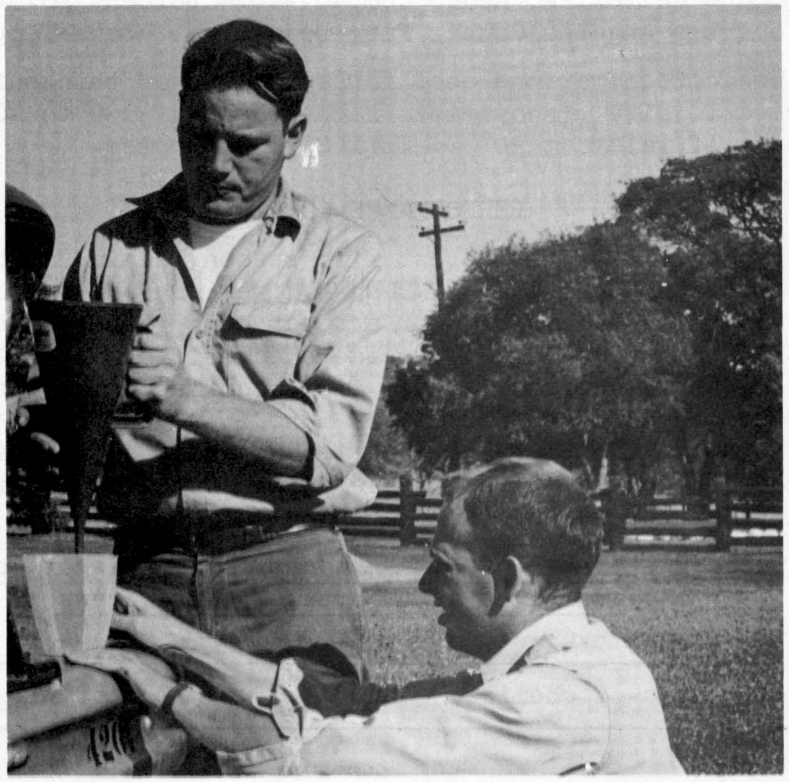

Figure 7.--Determining viscosity in the field with a Marsh funnel. The time required for the solution to run through the funnel gives an estimate of viscosity.

County), 420 gallon tank, 250 GPM pump; Paso Robles Forest Fire Station (San Luis Obispo County), 400 gallon tank, 250 GPM pump.

Viscous water--Algin, Keltex FF, Kelco Company--0.4 percent, solution in water. Tested by two U. S. Forest Service crews--Mount Shasta Ranger Station (Shasta-Trinity National Forest), 340 gallon tank, 80 GPM pump; Mohawk Ranger Station (Plumas National Forest), 400 gallon tank, 300 GPM pump; and by one California Division of Forestry crew--Flinn Springs Forest Fire Station (San Diego County), 500 gallon tank, 250 GPM pump.

ET-460-4--Dow Chemical Company--0.5 percent solution in water. Tested by one California Division of Forestry crew--Morgan Hill Fire Control Station (Santa Clara County), 400 gallon tank, 250 GPM pump.

CMC, 7-HP--Hercules Powder Company--0.5 percent solution in water. Tested by one Nevada Division of Forestry crew--Reno Fire Control Station, 160 gallon tank, 17 GPM pump.

CMC, S-75XH--E. I. DuPont de Nemours and Company--0.5 percent solution in water. Tested by one California Division of Forestry crew--Cathay Forest Fire Station (Mariposa County), 500 gallon tank, 250 GPM pump.

Algin-DAP--Diammonium phosphate, Monsanto Chemical Company--12 percent plus Keltex FF, Kelco Company--0.4 percent solution in water. Tested by one Los Angeles County Fire Department crew--Temple City.

The concentrations used for solutions of thickening agents were selected to give viscosities in the range of 100 to 400 centipoise. The viscosity of water at 20° C. is 1.005 centipoise.

PERFORMANCE ON FIRES

By the end of the forest fire season, algin had been used on 21 fires, ET-460-4 on 3, Hercules CMC on 4 fires, DuPont CMC on 2, bentonite foam on 9, and algin-DAP on 1, for a total of 40 fires. The one case where the algin-DAP was used did not provide enough information to judge its effectiveness on wild fires. Since fire occurrence for most of the cooperating stations was about 20 percent of normal, we had fewer fire tests than expected; however, the 40 fires experienced gave useful information on the effectiveness of the additives (table 2), and the five months of testing also brought out several operational problems.

Table 2.--Number of fires and effectiveness of chemical additives as reported by fire crews

Effectiveness of chemical	No. of fires
Superior to water	24
Same as water	5
Inferior to water	5
Undetermined 1/	6
Total	40

1/ For various reasons test crews could not evaluate chemical effectiveness on 6 fires.

Crews using viscous water reported a noticeable reduction in rekindling in both light and heavy fuels.

Viscous water tended to stick or cling to vertical surfaces, with an apparent good cooling and smothering effect.

Because runoff was less, viscous water usually tended to "go farther" than plain water--especially on foliage or on vertical surfaces such as walls or the trunks of trees or snags. On the other hand, in one test viscous water formed pools and did not spread over the surface of the logs and branches lying on the ground.

Viscous water was used on four structural fires with good results. Although three trucks with plain water had been unsuccessful in stopping one of these fires, it was brought under control soon after arrival of the fire truck. The material (0.4 percent Keltex FF) clung to the walls and eventually dried to a cellophane-like film. This film was thin but tough enough that it later was pulled away from the walls in sheets. There was little water damage since the viscous water did not soak into wood or fabric surfaces.

Bentonite foam appeared to be superior to water for stopping and holding fires burning in brush or small trees. It was used with good results in preparing lines for backfiring in these fuel types. Crews described it as having a blanketing effect that tended to smother the fire and insulate adjacent fuel. However, on fires in heavy grass or grain stubble, bentonite foam failed to penetrate into the matted material close to the ground. Consequently it let the fire creep underneath and eventually past the retardant line.

Both bentonite foam and viscous water reduced pumping efficiency. High pump pressures were required to produce usable nozzle pressures. However, good fog streams were produced with viscous water.

Both bentonite foam and viscous water created a clean-up and safety problem on and around the truck. Spills on the trucks are difficult to clean without removing most of the hose and loose equipment. Furthermore, the materials are slippery. Care must be taken in climbing on a truck or walking where the chemicals have been spilled. The nozzle also can become slippery and difficult to handle.

Trucks carrying water with additives have some limitations of use. For example, they cannot be used to wash down gasoline spills without producing a slippery road surface. Crews are reluctant to use bentonite foam on the inside of structures where furniture and household belongings can be salvaged; this does not seem to be a problem with viscous water. A truck which has carried bentonite foam cannot be used to haul drinking water without dumping the load and scrubbing out the tank.

CHARACTERISTICS OF FIRE FIGHTING CHEMICALS

VISCOUS WATER

The four viscosity agents used during the operational test, although different in chemical composition, work much like the powder used in making gelatine desserts at home. Since small quantities can adequately thicken the water, logistics are not a problem.

The degree of thickness depends on several factors, including the quantity and type of chemical used, temperature, salt content of the water, presence of other chemicals, and length of time that the mixed solution has been in storage.

Four to six pounds of thickening agent were required per 100 gallons of water to obtain 100 to 400 centipoise viscosities. We do not know as yet what viscosities are best, but we expect the optimum would differ somewhat with the fire situation. The early field tests indicated that suppressant effectiveness increased with viscosity, and later tests with high viscosity systems have given good results (Phillips, 1961). Test crews say viscous water below about 100 centipoise does not stick to vegetation and that above 400 centipoise gives difficulty in pumping with a centrifugal pump.

A small variation in the amount of thickening agent greatly affects viscosity of the solution (fig. 9, Appendix). For example, adding 1 pound per 100 gallons can more than double the viscosity. The viscosity of a solution with a given amount of agent may vary by nearly as much as 600 centipoise with different types of agents. The range is also due in part to variations in viscosity produced by changes in temperature--a 40-degree drop can double the viscosity.

All viscous water solutions lost viscosity in the presence of DAP. The viscosity of CMC-thickened water is greatly decreased when stored in a galvanized container which has not been coated with mastic or some other protective material. The small quantity of zinc present in galvanized pipes does not appear to be a problem.

In operational use, the viscosity of mixed solutions can easily be checked with a Marsh funnel (fig. 7) and corrected if necessary.

The viscosity agents are not toxic to animals and plants. In fact, one of the largest uses of CMC and algin is in the manufacture of food products such as ice creams and pie fillers. However, sometimes preservatives must be added to viscous water to control spoilage by bacteria during prolonged storage. These preservatives may be toxic themselves, but when added to viscous water they are so diluted that they do not present a problem (Brooks and Alyea, 1946).

The materials were found to vary considerably in corrosiveness. The alginate actually exhibited less corrosion than plain tap water to all metals commonly found on fire equipment (fig. 10, Appendix). In general, this also applied to both DuPont and Hercules CMC tested; however, both were moderately corrosive to galvanized surfaces.

The Dow ET-460-4 corroded copper and brass both in the operational test at Morgan Hill and in the laboratory. However, Dow chemists believe they have solved this problem with the addition of small quantities of a specific corrosion inhibitor. Other metals, including galvanized iron, showed little sign of corrosion.

In laboratory tests, none of the viscosity agents damaged surfaces that had been cleaned, painted, and oven-dried, even after samples were totally submerged for several weeks. Although there were several reports of "touch up" paint blistering in the field, it was probably no worse than if water had been allowed to stand on the paint for a prolonged period of time.

None of the viscous water solutions appear to be any more abrasive to pumps than plain water.

Because such small amounts of the dry powder are used (0.4 pounds per gallon of water) the weight of the solution, 8.3 pounds per gallon, is virtually the same as plain water.

CALCIUM ALGINATE GEL

Water thickened by algin to approximately 400 centipoise can be converted to calcium alginate gel by the addition of 1 part of 37 percent calcium chloride solution to about 300 parts of the algin water. The resultant gel has a viscosity of 3,500 to 5,000 centipoise. Varying the exact ratio of calcium chloride to algin determines the resultant viscosity.

BENTONITE FOAM

Swelling bentonite clay has been used with good results as a fire retardant for more than two years with air tankers. Its value as a retardant lies in its ability to set up into a stable slurry and retain water tenaciously for periods up to 2 or 3 hours under severe summer drying conditions (Phillips and Miller, 1959). When mixed with a small quantity of foaming agent such as Dowfax 2A1 and sprayed through an aerating nozzle, a stable, long-lasting foam with as much as a 7 to 1 expansion ratio can be produced.

The Dowfax 2A1 (also a wetting agent) penetrated the mastic tank lining, causing blisters that exposed the tank's metal to corrosion.

DIAMMONIUM PHOSPHATE

Diammonium phosphate is one of the more common agricultural fertilizers and is available from many sources. DAP has been recognized for many years as an excellent fire retardant and has been used extensively for structural and industrial fireproofing (Truax, 1939). Fuels treated with DAP characteristically char when subjected to an exterior source of heat but do not support flaming combustion.

The effectiveness of DAP in retarding fire appears to depend on the quantity of DAP relative to the weight and surface area of the fuel. While water solutions of DAP have been effective on grass and fine fuels, they have not been adequate to retard fires in larger fuels under severe burning conditions (Operation Firestop, 1954). Viscous water allows the DAP to stick to or remain on even heavy fuels in sufficient quantities to retard combustion.

Although DAP is not toxic, it tends to give off a slight amount of ammonia when applied to a fire. The ammonia may temporarily irritate the eyes of the nozzleman.

DAP is almost non-corrosive to mild steel, but it has proved to be somewhat corrosive to several other metals found on fire equipment, including aluminum, brass, and copper. Extent of corrosion depends largely on concentration, temperature, and length of storage. Corrosion inhibitors may solve this problem; however, little is known as yet about their effect on the viscosity of thickening agents.

MIXING, STORAGE, AND HANDLING

VISCOUS WATER

One advantage of the thickening agents tested is that only 20 pounds of any of the powdered viscosity agents per 500 gallons of water are required to produce viscosities in the range of 200 to 400 centipoise. Experienced crews find that they can mix this quantity with a jet mixer in 2 or 3 minutes, frequently while they are drafting a load of water. Although readily soluble if dispersed gradually into a jet of water, the materials form an almost impervious gelatin-like mass if poured all at once directly into a tank.

Both algin and CMC are organic compounds and are therefore subject to deterioration by bacteria when in storage. Spoilage, if it occurs, results in loss in viscosity and an odor that will make the firetruck unwelcome almost anywhere. Deterioration depends to a great degree on water source, temperature, and length of storage. It was not a problem with trucks located above 3,500 feet where temperatures were cool at night, but preservatives were necessary at stations located in the hotter foothills. About 100 parts per million of formaldehyde prevented spoilage. Laboratory samples without formaldehyde spoiled and lost viscosity within 3 weeks (fig. 11, Appendix). Eight ounces of 37 percent formaldehyde in 500 gallons of viscous water prevented spoilage in the field.

The Dow ET-460-4, unlike the other materials, is a synthetic organic compound and apparently presents no storage problem.

To insure complete mixing of the viscous solutions it is desirable to remove portions of the baffles normally used in the tanks of firetrucks. Wide openings between the compartments had to be provided to permit ease of circulation. Because of their higher viscosity, the mixed solutions do not slosh around in the tanks as does plain water and hence less baffling is needed.

This reduction in sloshing, however, results in a longer "recovery time" when the load does become unbalanced--as on curves or hills. One fire crew foreman said that his truck "rode heavier and harder" and that his springs did not seem to be adequate for the load even though none of the materials are much heavier in weight per unit volume than plain water.

CALCIUM ALGINATE GEL

Mixing of calcium alginate gel takes place in the nozzle. Algin thickened water is pumped through the hose as usual. In the tests, the calcium chloride solution was contained in small pressurized tanks in a backpack weighing about 20 pounds which was carried by the nozzleman (fig. 8). A 1/8 inch hose conducted the calcium chloride to the nozzle, where a valve operated by the nozzleman controlled the amount mixing with the algin thickened water. The two solutions form a gel immediately.

This mixing arrangement caused no additional loss in hose or nozzle pressure and permitted the application of straight or fog streams. By use of the calcium chloride control valve at the nozzle, the nozzleman could change quickly from viscous water to gel and back again, according to the fire situation. He could also control the viscosity of the gel by changing the valve opening.

The mixing arrangement is still in a crude developmental stage. Further refinement may produce a more convenient and more efficiently operated apparatus.

BENTONITE FOAM

Bentonite foam was mixed in much the same manner as viscous water. Logistics was more of a problem because 250-300 pounds of dry bentonite had to be mixed into the truck's water supply of 500 gallons and then a gallon of Dowfax 2A1 foaming agent added.

The top of the truck's tank was removed and replaced with inspection doors. Large holes were cut in the baffles, and new plumbing installed in the trucks so that the bentonite slurry could flow and circulate easily and uniformly throughout the tank. After the bentonite was thoroughly mixed by the jet, the foaming agent was

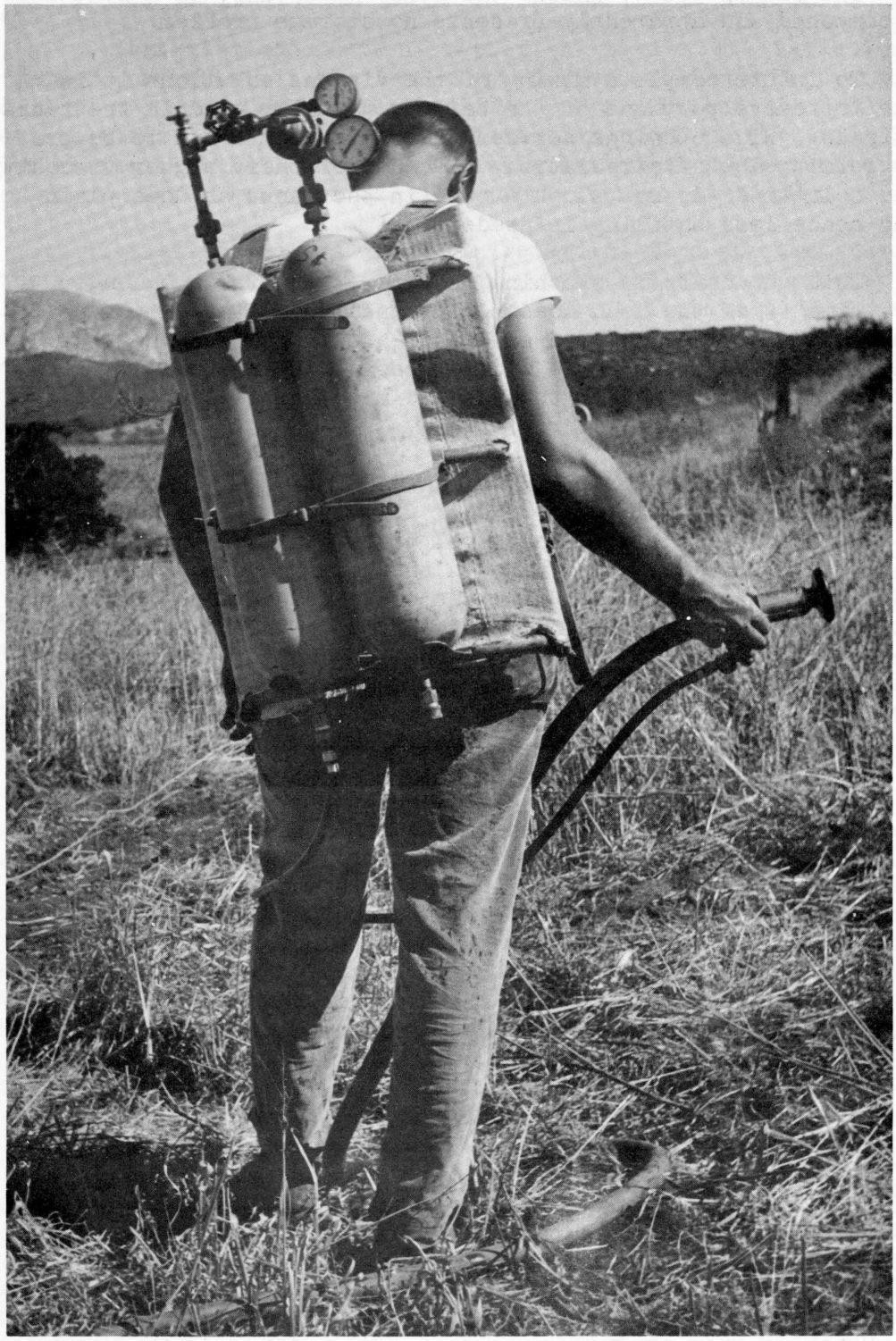

Figure 8.--Backpack arrangement and nozzle used to mix calcium chloride to algin to form calcium alginate gel.

poured through one of the inspection doors and stirred with a shovel. The mixture was then recirculated for a few minutes. Almost no foaming takes place during this recirculation if air entrainment is prevented.

DIAMMONIUM PHOSPHATE

DAP mixes readily with plain water or water thickened with CMC or algin, but it reduces viscosity a great deal within a few hours. This can be overcome by adding additional quantities of thickening agents.

COSTS

Viscous Water.-- The various thickening agents cost from 60 cents to a dollar per pound; 0.5 to 0.7 percent solutions cost about 2.5 to 7 cents per gallon.

Calcium Alginate Gel.--Since calcium chloride is inexpensive and little of it is used to make a gel, the cost per gallon of calcium alginate gel is virtually the same as for water and algin alone.

Bentonite Foam.--Bentonite slurry costs about 1.5 cents per gallon for the dry powder. The foaming agent adds about 1 cent per gallon, making a total of 2.5 cents per gallon for the bentonite foam mixture prior to expansion.

Viscous DAP.--Diammonium phosphate costs about 6 cents per pound. Mixed at the rate of 1-1/2 pounds per gallon to viscous water costing 3 to 4 cents per gallon, viscous DAP costs 12 to 14 cents.

CONCLUSION

These observational tests have left many unanswered questions. Particularly, we need more information on suppressant and retardant effects of these chemicals under different burning conditions and on different fuel types. However, results have been sufficiently uniform to draw several preliminary conclusions.

Viscous water reduced suppression time under several conditions and kept fires from rekindling. Although there were operational difficulties such as spoilage and slight corrosion of metal parts, most problems can probably be solved. The dry powder that makes the water thick can be mixed on the fireline in 1 to 5 minutes with a jet-type mixer which is easily installed on the truck.

Tests of calcium alginate gel, though done late in the year, look promising. The material will be tested on actual forest fires in 1961.

Bentonite foam also gave good results in knocking down the spread of brush fires and building backfire lines. But this material failed to penetrate heavy grass or grain stubble and did not stop fires in these fuels.

Diammonium phosphate has shown promise as a retardant in field tests, but has not been evaluated on wild fires.

The price is reasonable for all of these chemicals, ranging from 3 to 14 cents per gallon.

Future plans call for expanding the operational testing program to include more fire control crews and to cover more fuel types. Emphasis will be centered on viscous water and gel. Simultaneously, equipment development studies and laboratory research will be conducted to make sure that field crews have the latest information on equipment and techniques.

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APPENDIX--SUMMARY OF GROUND TANKER USE--1960

Number, name, and date of fire	Station	Fuel	Burning index 1/	Chemical	Effect and Comments
1. Star 7-11-60	Mariposa-CDF	Grass	Not available	Bentonite foam	"Better for line building."
2. No name 7-12-60	Morgan Hill-CDF	Grass	-20	ET-460-4	"Sticks to material well."
3. Hotlum 7-13-60	Mt. Shasta-USFS	Grass and sage	14	Algin	"Better than water."
4. No name 7-14-60	Paso Robles-CDF	Grass	Not available	Bentonite foam	"Water better for grass." "Chemical does not penetrate."
5. No name 7-14-60	Mt. Shasta-USFS	Second growth-poles	14	Algin	"Small mopup job--water would have done as well."
6. No name 7-14-60	Paso Robles-CDF	Med. brush and oak--So. Calif.	Not available	Bentonite foam	"Adheres better than water."
7. Polecat 7-17-60	Temple City-LACFD	Heavy mixed brush	27	Algin-DAP	No information--Had to evacuate entire area.
8. NP-31339 7-23-60	Mt. Shasta-USFS	Woodland	12	Algin	Fire was stopped. "Chemical superior to water."
9. Raner 7-26-60	Mohawk-USFS	Sawdust and lumber	17	Algin	"Chemical has definite cooling and smothering effect."

Number, name, and date of fire	Station	Fuel	Burning index 1/	Chemical	Effect and Comments
10. Hornitos Sch. 8-1-60	Cathay-CDF	Grass	Not available	CMC	"Has more cooling effect."
11. High 8-7-60	Mt. Shasta-USFS	Second growth-poles	15	Algin	Fire was stopped. "Unable to determine."
12. Cemetery 8-13-60	Mt. Shasta-USFS	Brush mixed with sage	14	Algin	"Chemical better than water."
13. Sawdust 8-14-60	Mt. Shasta-USFS	Sawdust	16	Algin	"Algin solution did not penetrate sawdust as well as water."
14. SPRR#6 8-17-60	Morgan Hill-CDF	Grass	Not available	ET-460-4	"Highly corrosive to metals and paint." "Same as water." "Hard to work with."
15. Peavine 8-18-60	Reno-NDF	Grass, sage	30	CMC	"Better smothering effect--no nozzle distance."
16. Schilling 8-20-60	Mt. Shasta-USFS	Mixed fir reproduction and brush	28	Algin	Fire was stopped. "Chemical as good or better than water."
17. Running Burn 8-20-60	Mariposa-CDF	Woodland	15	Bentonite foam	"Has blanket effect."
18. Homestake Mine 8-20-60	Morgan-Hill-CDF	Timber med. repro. and brush.	24	ET-460-4	"Forms pools--does not spread."

Number, name, and date of fire	Station	Fuel	Burning index 1/	Chemical	Effect and Comments
19. Donner Ridge 8-20-60 8-27-60	Reno-NDF	Timber med. reproduction and brush	70	CMC	"Has better suffocating effect but takes too long to mix--reduces nozzle stream."
20. Donner Ridge 8-29-60	Reno-NDF	Timber med. reproduction and brush	60	CMC	"Pump doesn't have enough pressure." "Has good coating effect."
21. Carney 8-30-60	Paso Robles-CDF	Structure	Not available	Bentonite foam	"Better than water." "Has ability to hold water."
22. Eagle Ranch 9-7-60	Paso Robles-CDF	Grass	26	Bentonite foam	"Equal to water."
23. Cartwright 9-7-60	Flinn Springs-CDF	Grass	10	Algin	"No real test."
24. Cowan 9-9-60	Flinn Springs-CDF	Baled hay	18	Algin	"Held moisture in hay."
25. Gilzean 9-9-60	Mt. Shasta-USFS	Brush mixed with sage	7	Algin	"Helped hasten the cooling down of the fire by slower evaporation."
26. Feus Flat 9-9-60	Mohawk-USFS	Mixed fir reproduction and brush	19	Algin	"Chemical has cooling effect, but does not penetrate."
27. Raymond "Y" 9-11-60	Cathay-CDF	Grass	28	CMC	"Prevents rekindling better than water."

Number, name and date of fire	Station	Fuel	Burning index 1/	Chemical	Effect and Comments
28. Sample 9-11-60	Flinn Springs-CDF	Structure	18	Algin	"Fire knocked down held."
29. MP-338 9-15-60	Mt. Shasta-USFS	Grass	19	Algin	"Plain water would have been as effective."
30. Krool 9-17-60	Mt. Shasta-USFS	Mixed fir reproduction and brush	19	Algin	"No better than water."
31. San Vicente 10-5-60	Flinn Springs-CDF	Med. brush and oak	14	Algin	"Algin slippery to work with but no rekindling."
32. No name 10-14-60	Reno-NDF	Piled logs	Not available	CMC	"No better than water."
33. Mi. Post 248.69 10-15-60	Paso Robles-CDF	Grass	11	Bentonite foam	"Same as water."
34. Brannon 10-16-60	Flinn Springs-CDF	Structure	18	Algin	"Mopup with chemical worked well."
35. Smith 10-17-60	Paso Robles-CDF	Woodland	21	Bentonite foam	"Seems to hide deep bedded fires." "No good for mopup."
36. Rossi #2 10-19-60	Paso Robles-CDF	Dump	11	Bentonite foam	"Sticks to trash." "Better than water."
37. Tilton 11-10-60	Flinn Springs-CDF	Structure	Not available	Algin	"Kept fire knocked down."

Number, name, and date of fire	Station	Fuel	Burning index 1/	Chemical	Effect and Comments
38. Guthrie 11-15-60	Flinn Springs-CDF	Structure	Not available	Algin	"Good cooling effect."
39. Huff 12-17-60	Flinn Springs-CDF	Truck load of furniture	Not available	Algin	"Algin solution was coating surface eliminating fuel for fire--did not damage furniture."
40. Tarbert	Flinn Springs-CDF	Structure	Not available	Algin	"Cooling and sticking effect." "Did not soak in--stopped fire without water damage."

1/ Burning Index Ranges: Low = 0 to 5; Moderate = 6 to 11; High = 12 to 18; Very high = 18 to 26; and Extreme = 27 to 100.

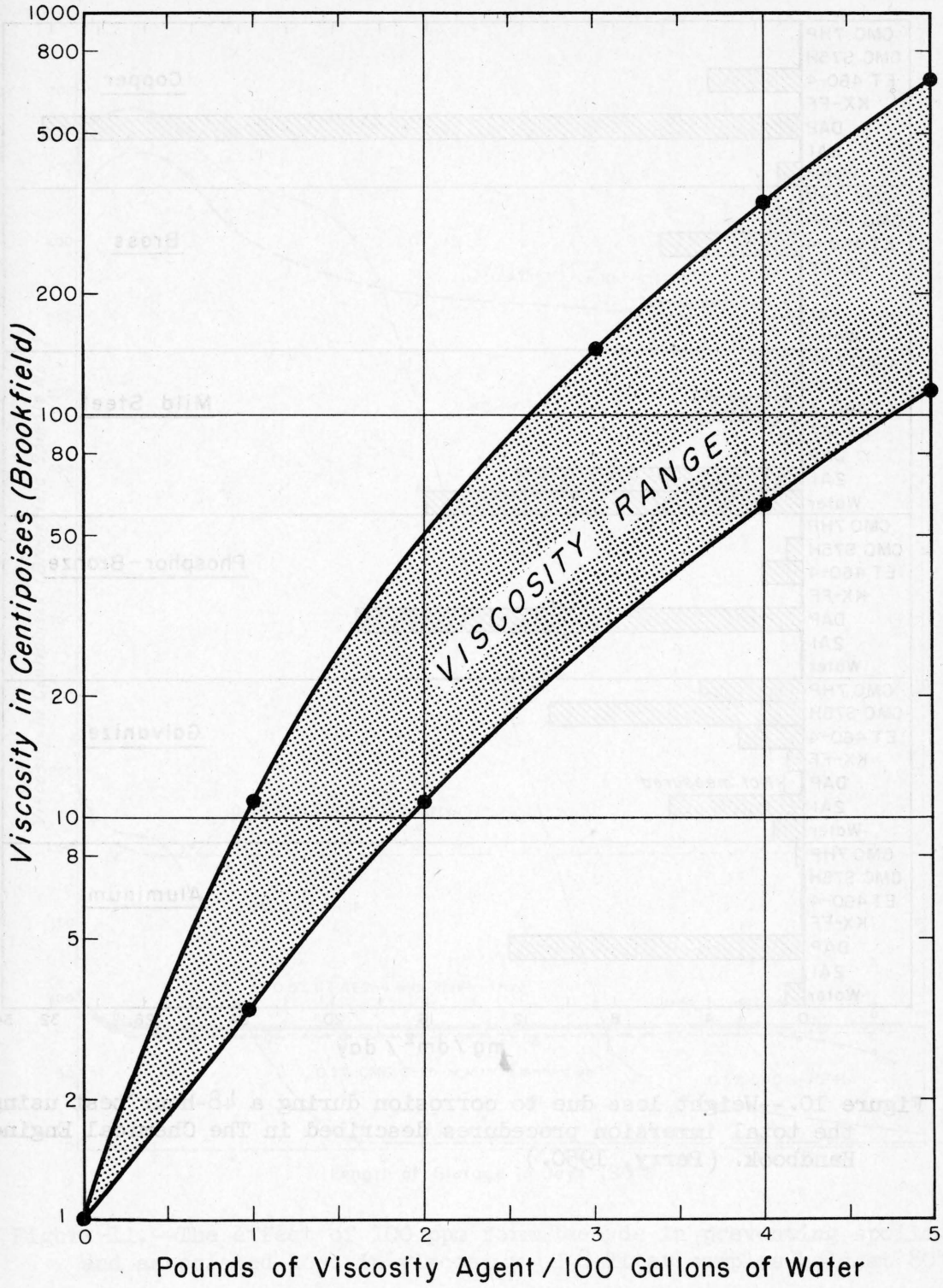

Figure 9.--Range of viscosities obtained with chemicals used during operational testing. Curves plotted from laboratory data obtained at the Pacific Southwest Forest and Range Experiment Station and from information supplied by manufacturers.

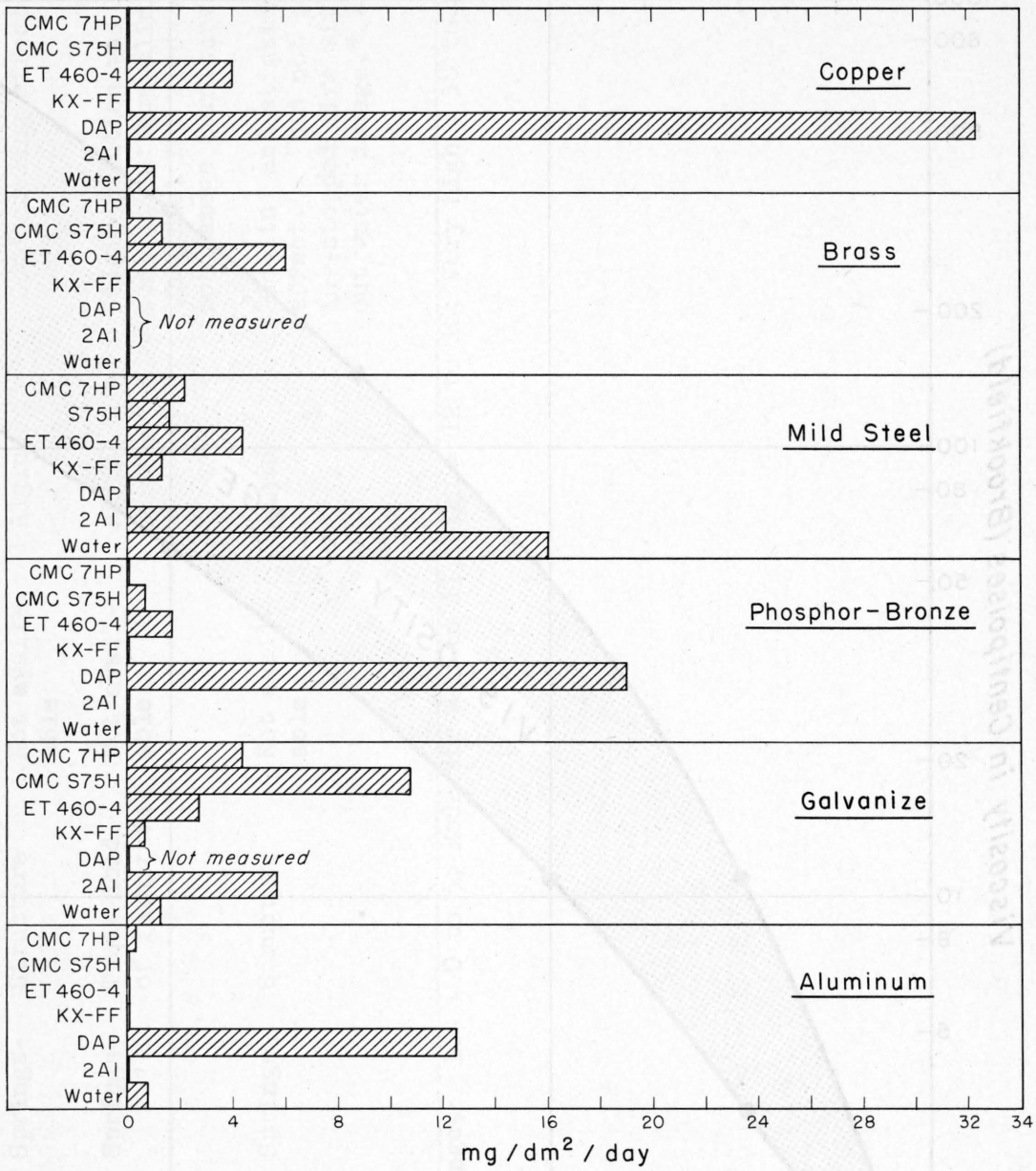

Figure 10.--Weight loss due to corrosion during a 48-hour test using the total immersion procedures described in The Chemical Engineer Handbook. (Perry, 1950.)

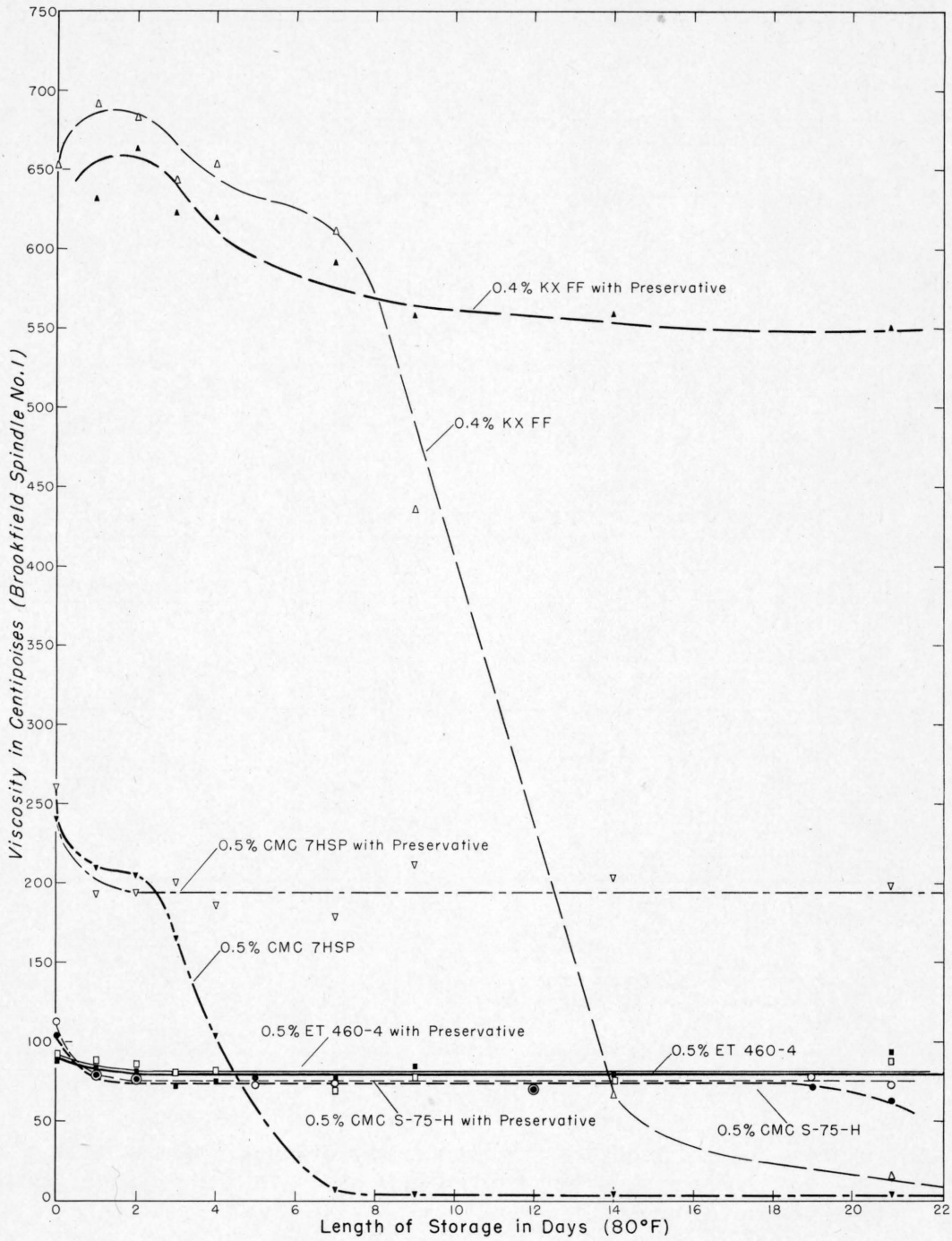
Viscosity in Centipoises (Brookfield Spindle No.1)
Length of Storage in Days (80°F)
0.4% KX FF with Preservative
0.4% KX FF
0.5% CMC 7HSP with Preservative
0.5% CMC 7HSP
0.5% ET 460-4 with Preservative
0.5% ET 460-4
0.5% CMC S-75-H with Preservative
0.5% CMC S-75-H

Figure 11.--The effect of 100 ppm formaldehyde in preventing spoilage and associated loss in viscosity (2.8 liter samples held at 80°F).